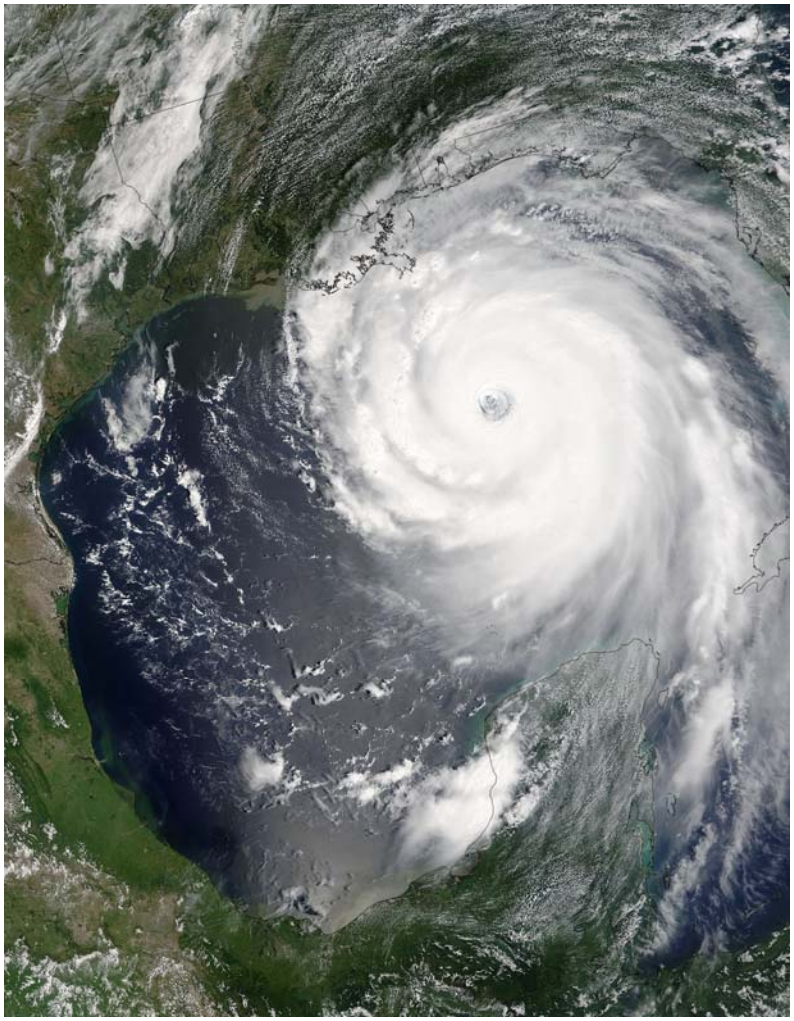
STORM SURGE

NOAA Hurricane Education

Student Activities & Teacher Resources



STORM SURGE

Preface:
The weatherperson on the news is talking about a tropical storm that is forming off the west coast of Africa in the Atlantic Ocean. Each update describes the strength, size, and path the storm is taking and provides a prediction of where and when it might make landfall in the United States. As the storm moves closer to the east coast of the US, predictions for the storms strength and accompanying storm surge are made. As the landfall for the storm becomes imminent, forecasts of the storm surge are made. A 10-15 foot storm surge is forecasted. What does this mean? Who and what is safe? Who needs to evacuate and when should they go?

Objectives:

1. Define storm surge
2. Investigate the effects of hurricane storm surge on low-lying areas near the coast
3. Determine the distance inland that the storm surge will reach
4. Explore the effects of various factors on storm surge

Acknowledgement:
Thanks to the staff in the NOAA's Office of Education who provided encouragement and assistance to make this storm surge activity a reality. Major thanks to Jason Woolard of NOAA's National Geodetic Survey (NGS) who created the maps needed for this activity. Thanks to all those that have played a role in my education. Thanks also to all my friends who have encouraged me along the way.

Beth Jewell
NOAA, Einstein Distinguished Educator Fellow

Written for the National Science Teachers Association Conference in Anaheim, April 2006

STORM SURGE

Background

Information for this section was taken from
http://www.nhc.noaa.gov/HAW2/english/storm_surge.shtml#actions

Storm Surge

A hurricane is a powerful, spiraling storm that begins over a warm sea, near the equator. When a hurricane hits land, it can do great damage through its storm surge, fierce winds, torrential rains, inland flooding, and huge waves crashing ashore. Storm surge (Figure 1), one of the most damaging components of a hurricane, is a massive dome of water often 50 miles wide that sweeps across the coast near the area where the eye of the hurricane makes landfall. This advancing surge of water combines with the normal tides to create the hurricane storm tide, which increases the mean water level, putting the tide line higher on the coast and flooding areas that are normally beyond the reach of the ocean. The storm surge acts like a *bulldozer* sweeping away everything in its path and flooding low lying areas. The stronger the hurricane the larger the storm surge will be. For those who live along the coast, storm surge is one of the most dangerous hazards in a hurricane. Understanding storm surge is essential in making decisions about development and planning evacuation routes as a hurricane approaches.

Figure 1. Schematic depicting the critical elements of a storm surge.

STORM SURGE

The inland reach or inundation caused by a storm surge is influenced by the slope of the continental shelf and shoreline elevation. A shallow sloping coastline will allow the storm surge to inundate coastal communities. Communities developed on a steeper coastline will not see as much surge inundation, although large breaking waves can still present major problem (Figure 2).

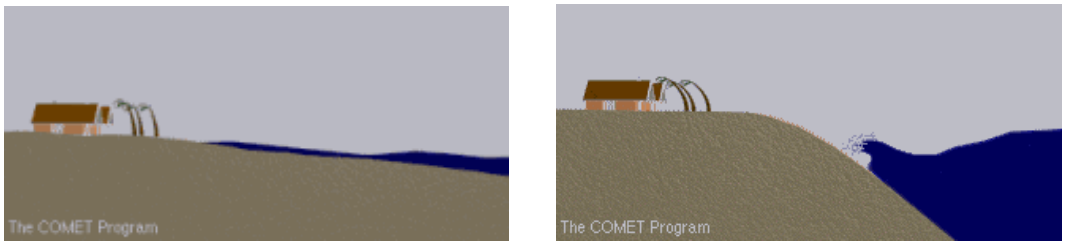


Figure 2. Contrasting hypothetical coastlines with different slopes to show the potential reach of a storm surge.

SLOSH Model

One tool used to evaluate the threat from storm surge is the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model (Figure 3). SLOSH is a computerized model run by the National Weather Service to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes. The model creates its estimates by assessing the pressure, size, forward speed, track, and wind data from a storm. Graphical output from the model displays color-coded storm surge heights for a particular area. The calculations are applied to a specific locale's shoreline, incorporating the slope of the coastline, unique bay and river configurations, water depths, bridges, roads, and other physical features. Emergency managers use the data from SLOSH to determine which areas must be evacuated to avoid the potentially deadly impacts of storm surge associated with a hurricane.

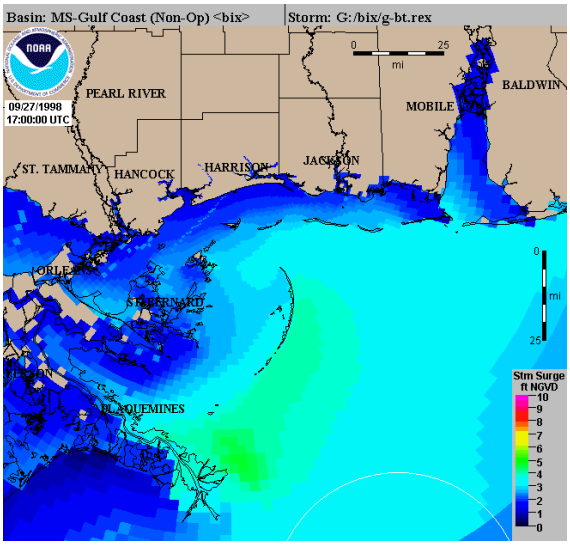


Figure 3. Output of the SLOSH model for the US Gulf Coast.

In general, the more intense the storm, and the closer a community is to the right-front quadrant of the storm (northeast), the larger the area that must be evacuated. The problem is always the uncertainty about how intense the storm will be when it finally makes landfall. Emergency managers and local officials balance that uncertainty with the human and economic risks to their community if evacuation does not take place.

Wave and water current action associated with the surge also causes extensive damage. Water weighs approximately 1,700 pounds per cubic yard; extended pounding by frequent waves can demolish any structure not specifically designed to withstand such forces. The currents created by the surge combine with the action of the waves to severely erode beaches and coastal highways. Many buildings withstand hurricane force winds until their foundations, undermined by erosion, are weakened and fail (Figure 4).

Figure 4. Eroded foundation and resulting collapse of a building on the coast following a hurricane-induced storm surge.

Topographic and bathymetric maps allow us to view topography of the land and bathymetry of the ocean by the use of contour lines. These maps illustrate where the relief is gradual or dramatic over a distance. Student understanding of the graphical representation of topographic and bathymetric maps is necessary before attempting this activity. This activity was designed with the expectation that students understand topographic and bathymetric maps. If you need to introduce or review this concept, USGS has a good lesson that will assist you.
http://interactive2.usgs.gov/learningweb/teachers/mapsshow_lesson4.htm

LIDAR
Information for this section was taken from:
http://www.csc.noaa.gov/products/sccoasts/html/tutlid.htm and
http://www.csc.noaa.gov/crs/rs_apps/sensors/lidar.htm

The maps that have been included with this activity have been produced using LIDAR (Light Detection and Ranging) data and GIS technology. LIDAR is a remote sensing system used to collect topographic data. This technology is being used by the National Oceanic and Atmospheric Administration (NOAA) and other scientists to document topographic changes along shorelines. These data are collected with aircraft-mounted lasers capable of recording elevation measurements at a rate of 2,000 to 5,000 pulses per

second and have a vertical precision of 15 centimeters (6 inches) (Figure 5). After a baseline data set has been created, follow-up flights can be used to detect shoreline changes. These shoreline changes are particularly important to map following a hurricane or other events that cause significant shoreline alteration. LIDAR data products can be used to address a number of topographic issues.

Figure 5. Illustration depicting a plane flying with a LIDAR unit scanning land below.

Storm Surge Safety

Information for this section was taken from:
http://www.nhc.noaa.gov/HAW2/english/storm_surge.shtml#actions

- Select the nearest possible evacuation destination, preferably within your local area, and map out your route. Do not get on the road without a planned route or a place to go.
- Minimize the distance you must travel to reach a safe location; the farther you have to drive, the higher the likelihood of encountering traffic congestion and other problems on the roadways.
- Choose the home of the closest friend or relative outside a designated evacuation zone and discuss your plan with them before hurricane season.
- You may also choose a hotel/motel outside of the vulnerable area.
- If neither of these options is available, consider the closest possible public shelter, preferably within your local area.
- Use the evacuation routes designated by authorities and, if possible, become familiar with your route by driving it before an evacuation order is issued.
- Contact your local emergency management office to register or get information regarding anyone in your household whom may require special assistance in order to evacuate.
- Prepare a separate pet plan, most public shelters do not accept pets.
- Prepare your home prior to leaving by boarding up doors and windows, securing or moving indoors all yard objects, and turning off all utilities.

- Before leaving, fill your car with gas and withdraw extra money from the ATM.
- Take all prescription medicines and special medical items, such as glasses and diapers.
- If you live in an evacuation zone and are ordered to evacuate by state or local officials, do so as quickly as possible. Do not wait or delay your departure, to do so will only increase your chances of being stuck in traffic, or even worse, not being able to get out at all.
- Expect traffic congestion and delays during evacuations. Expect and plan for significantly longer travel times than normal to reach your family's intended destination.
- Stay tuned to a local radio or television station and listen carefully for any advisories or specific instructions from local officials. Monitor your NOAA weather radio.

Resources

- NOAA Coastal Services Center FAQ— provides frequently asked questions about and answers to hurricane evacuation studies, evacuation zone data, storm surge data, and shelters. http://www.csc.noaa.gov/hez_tool/faq.html
- SLOSH model— http://www.nhc.noaa.gov/HAW2/english/surge/slosh.shtml
- Hurricane strength- http://www.nhc.noaa.gov/HAW2/english/high_winds.shtml
- *Surge of the Storm*— hands on activity in which students use water, sand, and blocks of wood to model the affects of storm surge on a coastline. http://seacoos.org/Community%20and%20Classroom/hurricane-classroom/surge-online
- Bathymetric maps— This NOAA coastal relief gridded database provides a comprehensive view of the US Coastal Zone. http://www.ngdc.noaa.gov/mgg/coastal/coastal.html
- Students will need to look at maps of the east coast of the United States including the Gulf of Mexico area in order to answer their conclusion questions. You can find these at Mapquest.com
- Topographic maps can be purchased from USGS— http://store.usgs.gov/
- GIS data to produce your own maps can be found at http://ekman.csc.noaa.gov/TCM/ NOAA's Jason Woolard from the National Geodetic Survey (NOS) was instrumental in the production of the maps included in this activity. Should you need some assistance he would be more than happy to lend a hand. Jason.woolard@noaa.gov
- Max Mayfield, director of the National Hurricane Center, discusses storm surge http://www.nhc.noaa.gov/HAW2/pdf/storm_surge.mp3

STORM SURGE

For the Teacher

Grade Level: 7-12
Duration of Activity: 1- 2 days

National Science Education Standards (NSES) and Ocean Literacy Standards (OL):
5-8 NSES Standards – Earth Science – Standard D
Structure of the Earth System – Global patterns of atmospheric movement influence local weather. Oceans have a major effect on climate, because water in the oceans holds a large amount of heat.
5-8 OL Standards – Influence on Weather and Climate

5-8 NSES Standards – Science in Personal and Social Perspectives – Standard F
Natural Hazards – Internal and external processes of the earth system cause natural hazards, events that change or destroy human and wildlife habitats, damage property, and harm or kill humans. Natural hazards include earthquakes, landslides, wildfires, volcanic eruptions, floods, storms, and even possible impacts from asteroids.
5-8 OL Standards – Influence on Weather and Climate

9-12 NSES Standards – Earth Science – Standard D
Energy in the Earth System - Heating in earth's surface and atmosphere by the sun drives convections within the atmosphere and oceans, producing winds and ocean currents.
9-12 OL Standards – Influence on Weather and Climate, Ocean Shapes the Earth

9-12 NSES Standards – Science in Personal and Social Perspectives – Standard F
Natural Hazards – Normal adjustments of earth may be hazardous for humans. Humans live at the interface between the atmosphere driven by solar energy and the upper mantle where convection creates changes in the earth's solid crust. As societies have grown, become stable, and come to value aspects of the environment, vulnerability to natural processes of change has increased.

Natural and human induced hazards present the need for humans to assess potential danger and risk. Students should understand the costs and trade-offs of various hazards. The scale of events and accuracy with which scientists and engineers can predict events are important considerations.
9-12 OL Standards – Influence on Weather and Climate, Oceans Shapes the Earth

Tips

- This activity was designed with the expectation that students understand topographic and bathymetric maps. If you need to introduce or review this concept, USGS has a good lesson that will assist you.
http://interactive2.usgs.gov/learningweb/teachers/mapsshow_lesson4.htm
- Students will need some background information about storm surge, which is included in this packet.
- It is important to keep in mind that many parameters affect the ultimate height of a storm surge. Storm surge has been simplified for this activity so students will first obtain a basic understanding. Later, factors affecting storm surge are presented to the students. The *Surge of the Storm* is a hands-on activity in which students use water, sand, and blocks of wood to model the effects of storm surge on a coastline.
- Consider starting this lesson by bringing in magazines and newspapers articles about hurricanes. Of course if you teach about hurricanes during the fall, it is likely they will be in the news and class discussions will naturally start from there.
- This activity contains images of the South Carolina and Maine coastlines, created using a laser-imaging and mapping technology called LIDAR. Because LIDAR works somewhat like a camera both land elevation and man-made objects are captured on a LIDAR-produced map. For example, you will see buildings and piers on the images of the SC and ME coastlines along with land elevation contour lines. These coastlines were chosen for their contrasting topography- a gently sloped coastline and a steep coastline. This is important for students to understand as they are trying to make sense of the maps.
- It is important that the students understand that the slopes of the two coastlines are different. You can find bathymetric maps at
http://www.ngdc.noaa.gov/mgg/coastal/coastal.html
- Students are asked to explore the topography maps. This can be done in small groups or as full class discussion. Students should be able to identify buildings, roads, and the contour interval. They should be able to determine if the topography of the coast is gentle or steeply sloped. On the South Carolina coast the contour lines show a dune feature. It is important they see this as it will come into play later.
- Because the city of New Orleans is below sea level, a levee system was built around the city to keep the ocean water out. The strength of the storm surge associated with Katrina broke through levees, allowing water to flow into the city's lowest elevation areas. The areas that were flooded were below sea level and the water that poured into these areas had to be pumped back over the remaining levees, flooding the city for weeks.
- Students will need to look at the east coast of the United States in order to answer their conclusion questions, these maps can be found at www.mapquest.com.
- Topographic maps can be purchased from USGS- http://store.usgs.gov/
- GIS data to produce your own maps can be found at http://ekman.csc.noaa.gov/TCM/

NOAA's Jason Woolard from the National Geodetic Survey (NOS) was instrumental in the production of the maps included in this activity. Should you need some assistance he would be more than happy to lend a hand. Jason.woolard@noaa.gov

STORM SURGE

Answers to Student Conclusion Questions

1. Describe storm surge in your own words.
Water is pushed toward the shore by the force of the winds swirling around the storm.

2. How does a hurricane produce a storm surge?
The intense strength pushes water ahead of the storm.

3. Was any area safe from the storm surge on your maps? Why or why not?
Damage other than erosion of cliffs in Maine is due to the lack of human influence and steep elevation gradient. In South Carolina the damage would be much more significant. A storm surge of 10 feet or higher would result in compromised building foundations and local flooding. A storm surge over 20 feet would result in water rising over the dune and flooding the lower lying areas behind the dune with no way to drain back into the ocean.

4. Why do people build beach houses on stilts? Is a beach house on 10 foot stilts safe from an 8 foot storm surge? Why or why not?
Houses built on stilts help to protect the house from flooding. Although the house itself would not be affected by an 8 foot storm surge, the foundation would be comprised due to the erosion.

5. What elements of a hurricane are influential in causing storm surge?
Winds, tides, topography, strength of the storm.

6. What elements are influential in the impact of the storm surge on a coastline?
Barrier islands, marshes, wetlands

7. How would storm surge effect a low lying coastline like a marsh as compared to a cliff shoreline?
A low lying marsh area would be subject to flooding while the cliff shoreline would provide a barrier to flooding by deflecting the surge back to the ocean.

8. What role has climate change played in making coastlines more susceptible to storm surges?
As sea level rises, the coastline moves farther inland thus closer to developed areas. These developed areas are now more at risk from storm surge.

9. Many years ago, there were no laws that forced people to evacuate before a hurricane struck. Now there are mandatory evacuation laws in place. Is this good? Why?
People could be trapped in an area that was flooded from storm surge that rose over or broke through a dune or levee if they were to stay in the area. This makes it difficult for them to get the food and supplies they need and hampers rescue efforts.

10. The predicted height of a storm surge is based on the mean tide level, taking into account when the storm is predicted to make landfall and the tides for that time. How might the predicted height of a hurricane storm surge be altered if the speed (forward motion) of the storm speeds up or slows down? What other factors will come into play?
The time of the high and low tide comes into play. If the storm surge prediction was made for a time of a low tide but actually makes landfall around high tide, the amount of the coastline that is affected will be farther inland, more flooding than what was initially expected would occur.

11. Explain how barrier islands will affect the storm surge height.
Barrier islands would help to soften the blow of a storm surge to the mainland, deflecting the wave back to the ocean much like a cliff would do.

12. Your maps did not show a river feature, explain what would happen inland and up the river as a result of hurricane storm surge.
The storm surge would travel farther inland because the interface where the river meets the sea is at sea level and there is no barrier to block the storm surge.

13. What recommendations would you make to a developer who is interested in building on coastal properties?
Although a 30 foot storm surge is rare, developing at elevations of 30 feet would almost ensure one that the building would be safe from storm surge. In the SC example; this would mean putting the building on the back side of the dune, taking away the view of the ocean, lower the value of the property.

14. Discuss the effects of pollutants and runoff from the land on the surrounding aquatic life after a storm surge retreats.
As the water retreats, pollutants from land such as oil, plastics, or fertilizers will be carried back to the ocean. Oils coat the surface of organisms, the plastics can be mistaken for food by some organisms or cause entanglement, and fertilizers can cause algal blooms.

15. Discuss the effects of the salt water on the land.
Bodies of fresh water will become more saline. Salt water is toxic to most plants, drying them out due to osmotic movement through the cell membranes, which causes water to flow out of the cells.

16. Discuss the effects of human activity on the impacts of storm surge on a coastal community.
As humans build on the coastlines, the natural buffers are reduced. Roads and buildings cover the naturally porous land and replace it with a surface area that causes water to run

off. The levee system in New Orleans essentially has created an artificial living space for humans. The area is below sea level with the levees holding back the ocean water. When a storm surge breaks over the levees, water is then trapped by the levees, pools in the lower-than-sea-level areas and is further prevented from returning to the ocean by being trapped behind the levees. As coastal areas are increasingly developed, more and more property and human lives are put a risk to the effects of storm surge, thus increasing the economic losses associated with hurricanes will increase.

17. Why might storm surge be a concern to Mobile, Alabama?
Mobile, Alabama is low lying and adjacent to a bay; water from storm surge would be funneled into this area.

18. How is Port St Lucie, Florida protected from a direct hit by a storm surge?
This area is protected by a barrier island system. As a storm surge approaches, the barrier island will deflect much of the energy back to the ocean, protecting the mainland behind.

19. Are all storm surges associated with hurricanes?
All storms will produce a storm surge; the intensity is much greater with a hurricane, therefore more noticeable and ultimately more damaging.

STORM SURGE

Student Activity

How does hurricane storm surge affect the low-lying areas along a coast?

The local weatherperson is talking about a tropical storm that is forming off the west coast of Africa in the Atlantic Ocean. Updates describe the strength, size, and path the storm (Figure 1) is taking, providing a prediction of where and when it might make landfall in the United States. As the storm moves closer to the east coast of the US, predictions for the storms strength and associated storm surge are made. As landfall nears, forecasts of the storm surge are made. A 10-15 foot storm surge is forecasted. What does this mean? Who and what is safe? Who needs to evacuate and when should they go?

Figure 1. Predicted storm path.

Objectives:

2. Define storm surge
3. Investigate the effects of hurricane storm surge on low-lying areas near the coast
4. Determine the distance inland that the storm surge will reach
5. Explore the effects of various factors on storm surge

Materials:

a. Copy of South Carolina Land Elevation map
b. Copy of South Carolina Laser Intensity map
c. Copy of Maine Land Elevation map
d. Copy of Maine Laser Intensity map
e. Colored pencils
f. United States east coast map
g. Bathymetric maps- http://www.ngdc.noaa.gov/mgg/coastal/coastal.html

STORM SURGE

Focus Question: How does the storm surge of a hurricane affect the low-lying areas along the coast?

Procedure:

1. Look at the land elevation maps of the South Carolina and Maine coastlines. What are the contour intervals? What features do you see in each map? Keep in mind that these maps were produced using LIDAR data and man-made objects such as buildings and piers will appear on the map along with contour lines.
2. Look at the Laser Intensity maps from South Carolina and Maine. Although they look very similar to black and white photographs, these maps are actually an image created from the strength of reflectivity of the laser. How has this enhanced your perspective of the contour map?
3. **Storm surge** is water that is pushed toward the shore by the force of the winds swirling around the storm. This advancing surge combines with the normal tides to create the storm surge, which increases the mean water level (zero contour line). This means the tide line is now higher up on the beach. If the surge is great enough, flooding will occur. To illustrate the landward movement of the storm surge, use colored pencils and the following key to color in each of the elevation bands on both of your contour maps: red: 0-5 feet, orange: 6-10 feet, yellow: 11-15 feet, green: 16-20 feet, blue: 21-25 feet, purple: 26-30 feet.
4. Look at your maps once again. What damage would a 5 foot storm surge inflict on this area? 10 foot? 15 foot? 20 foot? 25 foot?
5. If a hurricane hit the coast with a 5 foot storm surge, how would the water drain back to the ocean once the storm had passed?
6. Notice on your SC map that when you read the contours starting from the ocean and going landward they read 0, 5, 10, 15, 20, 15 feet. What topographical feature is represented by this pattern? Describe what would happen to the water if a hurricane with a 25 storm surge were to hit this area? What problems do you see for the area behind the dunes? How might the water drain out of the area? Essentially this is what occurred in New Orleans when hurricane Katrina struck in 2005.
7. Look at the bathymetric maps of these two locations. What correlations can you draw about bathymetric features of each of the areas and the storm surge impact on the coast?

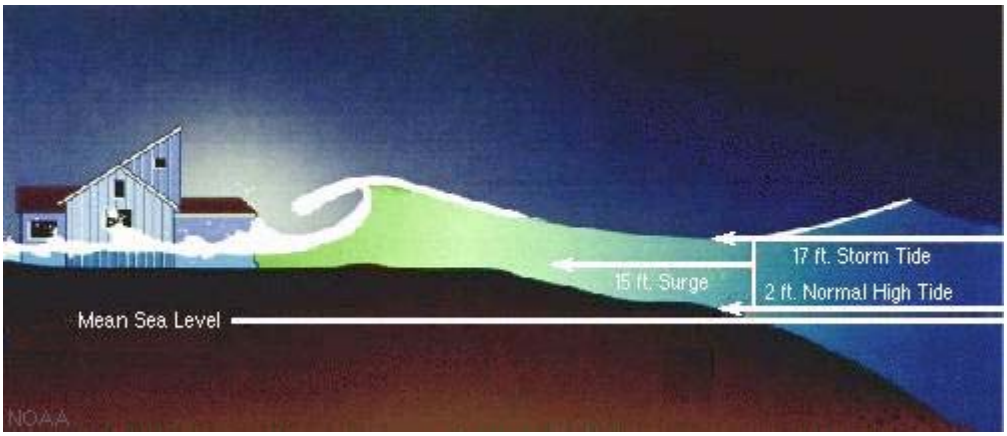
STORM SURGE

Conclusions:

1. Describe storm surge in your own words.
2. How does a hurricane produce a storm surge?
3. Was any area safe from the storm surge on your maps? Why or why not?
4. Why do people build beach houses on stilts? Is a beach house on 10 foot stilts safe from an 8 foot storm surge? Why or why not?
5. What elements of a hurricane are influential in causing storm surge?
6. What elements are influential in the impact of the storm surge on a coastline?
7. How would storm surge affect a low lying coastline like a marsh as compared to a cliff shoreline?
8. What role has climate change played in making coastlines more susceptible to storm surges?
9. Many years ago, there were no laws that forced people to evacuate before a hurricane struck. Now there are mandatory evacuation laws in place. Is this good? Why?
10. The predicted height of a storm surge is based on the mean tide level, taking into account when the storm is predicted to make landfall and the tides for that time. How might the predicted height of a hurricane storm surge be altered if the speed (forward motion) of the storm speeds up or slows down? What other factors will come into play?
11. Explain how barrier islands will affect the storm surge height.
12. Your maps did not show a river feature, explain what would happen inland and up the river as a result of hurricane storm surge.
13. What recommendations would you make to a developer who is interested in building on coastal properties?
14. Discuss the effects of pollutants and runoff from the land on the surrounding aquatic life.
15. Discuss the effects of the salt water on the land.
16. Discuss the effects of human activity on the impacts of storm surge on a coastal community.
17. Why might storm surge be a concern to Mobile, Alabama?
18. How is Port St Lucie, Florida protected from a direct hit by a storm surge?
19. Are all storm surges associated with hurricanes?

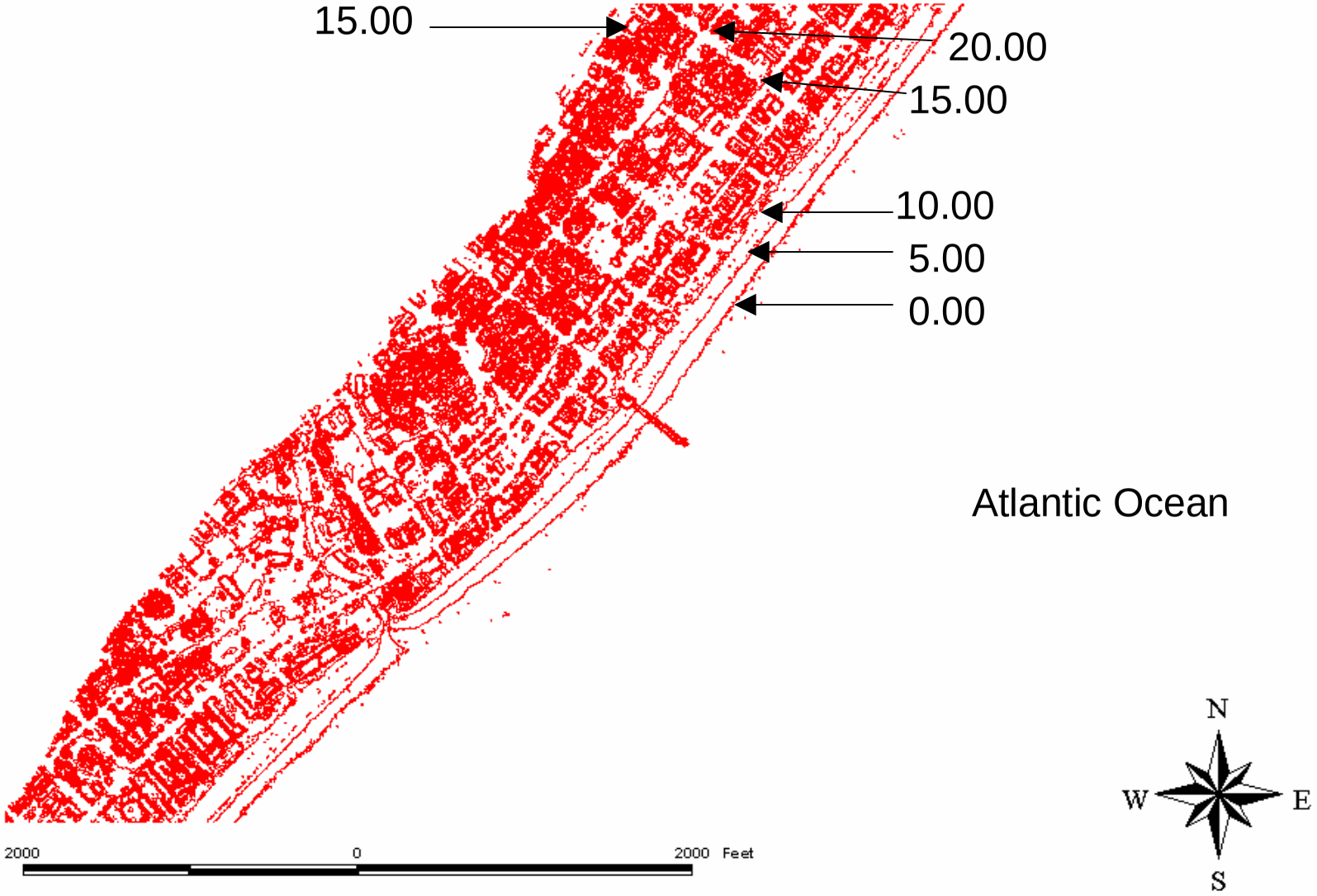
Further Extension Activity

Repeat this activity using a contour map from where you live, vacation or would like to vacation. Develop a personal emergency plan for the type of severe weather you may encounter if a hurricane were to strike where you live or vacation. Consider worst case scenarios and include plans for preparation, immediate action when the severe weather strikes and long term conditions. What contingencies should be planned? For example, it is important to know which roads will flood early limiting evacuation routes and forcing people to use alternate routes. Students may develop a severe weather plan as a group activity. Students could assume the roles of the various planners, public safety officials or weather forecasters.



South Carolina Land Elevation Map

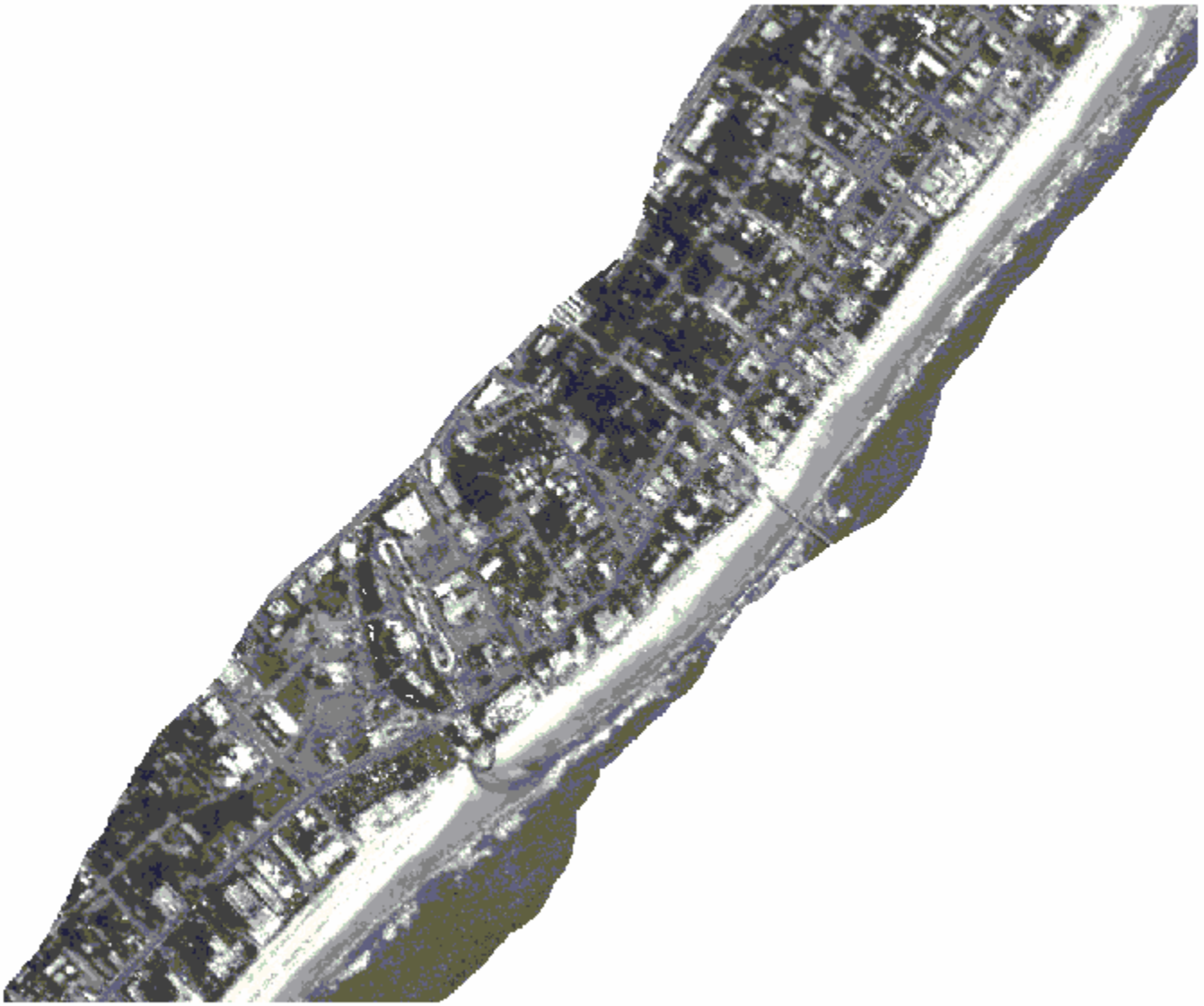
33.41 N, 78.53 W



Contour intervals given in feet

Laser Intensity - SC

33.41 N, 78.53 W



2000 0 2000 Feet

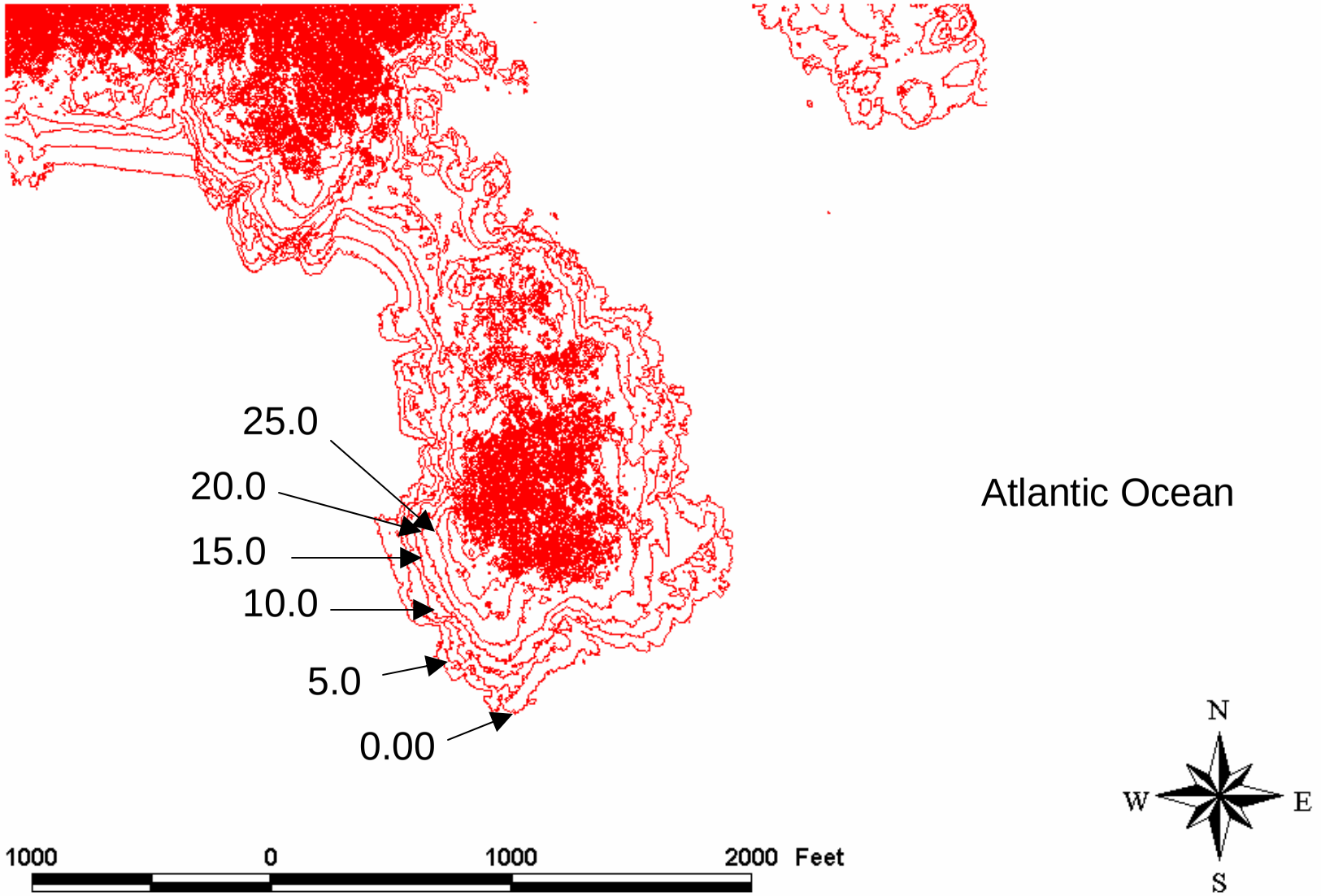
N

W E

S

Maine Land Elevation Map

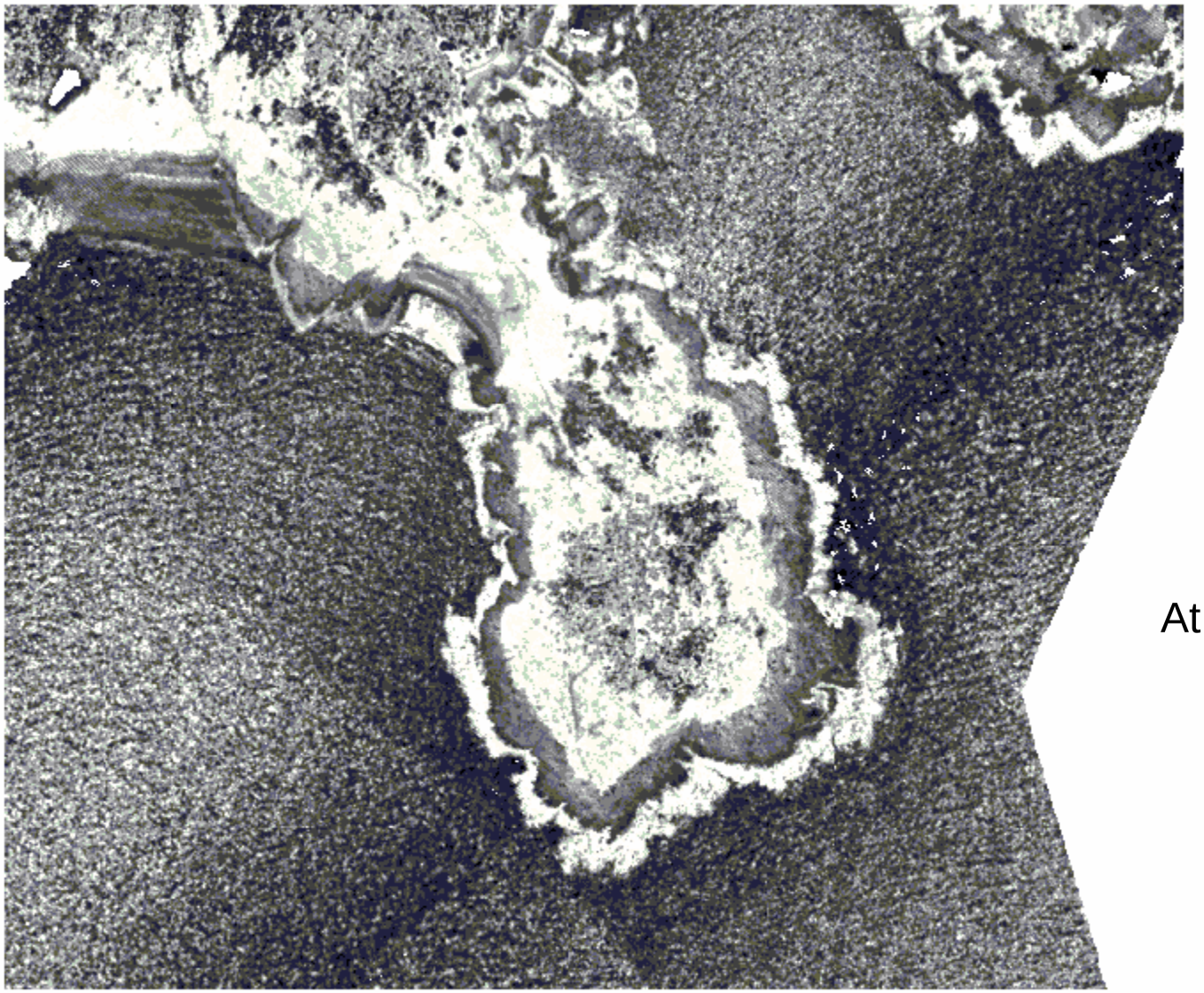
33.41 N, 78.53 W



Contour intervals given in feet

Maine Laser Intensity Map

33.41 N, 78.53 W



Atlantic Ocean

1000 0 1000 2000 Feet